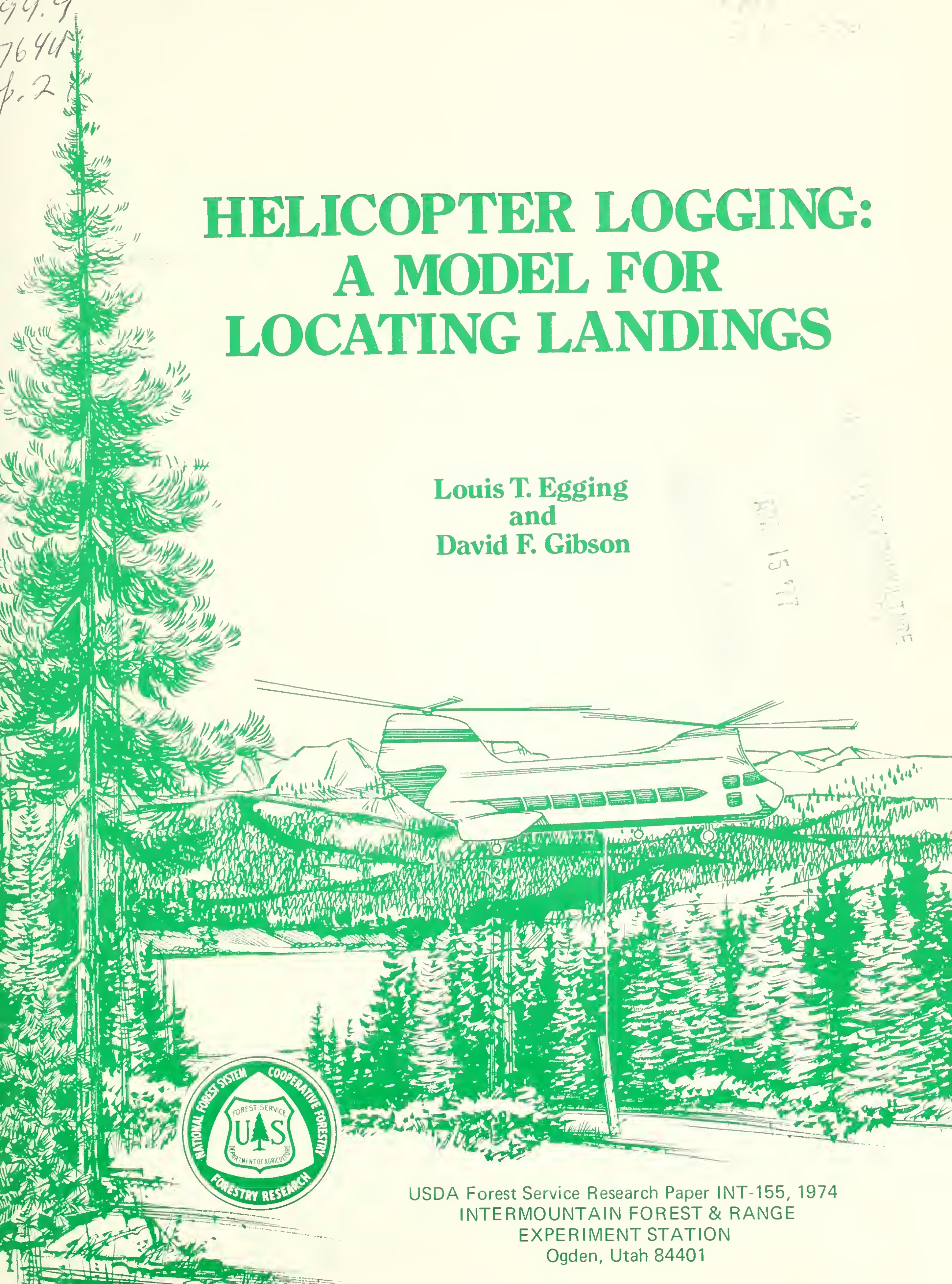

HELICOPTER LOGGING: A MODEL FOR LOCATING LANDINGS

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CONTENTS

ABSTRACT

Presented are a model and an accompanying computer program that optimally locate landing areas for a helicopter logging operation. Given a haul road, unit centroids, volumes of timber to be harvested, and helicopter operating parameters, landings are located so as to minimize yarding, hauling, and landing construction costs. The model considers constraints such as areas that are not suitable for landings and topographical obstacles. Written in FORTRAN IV, the computer program affords several evaluation and output options. Two examples are provided.

INTRODUCTION

In recent years, helicopter logging has emerged from experimental stages to become a viable alternative to conventional harvesting systems. Helicopter logging has a number of attractive advantages under certain conditions and management objectives. These include minimal environmental impact and the ability to harvest heretofore inaccessible timber. As a result, the volume of timber harvested by means of helicopter systems has been increasing steadily each year.

Binkley [1972] Edholm (1973, 1974), and Stevens (1972, 1973) have reported the general production and cost aspects of helicopter logging. The studies show that helicopter logging is expensive and warrants efforts to design an operating system in the most economical manner possible. Gibson (1974) developed a cost model that, given parameters of a system, specified optimum refueling of the aircraft.

This paper presents another tool for designing and managing a helicopter logging sale by presenting a computer model that specifies the number and location of landings to which the timber should be yarded. Considerations include areas not suitable for landings, and flight path restrictions such as ridges or other obstacles. Alternative landing sites are evaluated by total cost of yarding, landing construction, and hauling.

STATEMENT OF THE PROBLEM

Timber felled and "marked for turns" (logs identified to be grouped together as a load) is yarded to landings that are located on or in close proximity to a preexisting road. The timber is then loaded on trucks and hauled to the mill. Location and the number of landings affect (1) yarding costs, (2) landing construction costs, and (3) hauling costs. Topographical features often influence flight paths and landing selection. This paper is addressed to the problem of locating landings to minimize costs and yet satisfy constraints.

Locating helicopter landings is a special case of the generalized Weber problem, which is concerned with locating facilities within a given space so as to minimize a cost function. Many variations of the problem have been defined and include the consideration of various measures of distance (rectilinear, Euclidean, square of Euclidean), costs, and other features. Notable treatments of the problem include those by Kuhn and Kuenne (1962), Bellman (1965), Cooper (1963, 1968), Hakimi (1964), Levy (1967), and Cabot and others (1970).

The treatment presented in this paper is unique in several respects. First, although Euclidean distances are used to determine yarding costs, obstacles may be present: a flight path may be a series of linear line segments routed around a ridge or other obstacle, as opposed to a single path. Secondly, the costs of constructing landings has not only a fixed component, but also a variable one as well, which is dependent upon the amount of timber yarded to it. Also, a second transportation cost--the hauling cost--is included.

The extensive literature related to the generalized Weber problem will not be reviewed here. Nor will the computational techniques previously developed be enriched to extend the model to more general applications. This may be done in a subsequent paper. The purpose of this paper is to define the problem of designing and managing helicopter logging systems and to provide a FORTRAN IV program for locating landings.

A statement of the problem follows:

Given:

1. a haul road that can be represented by a set of linear line segments,
2. units to be logged, together with their respective centroids and timber volumes,
3. road segments infeasible for landing locations,
4. ridges or other topographical obstacles (which can be represented by linear line segments) that may preclude direct flight paths between units and landings, and
5. system costs and operating characteristics,

find:

1. the number of landings,
2. the location of landings on the haul road, and
3. the allocation of logging units to landings,

so as to minimize the sum of:

1. yarding cost,
2. landing construction cost, and
3. hauling cost.

Figure 1 illustrates a helicopter logging layout with four units and a haul road represented by eight linear line segments. On two of the units, ridges may prevent direct flights to landings. The problem is to find the number (1, 2, 3, or 4) and location of landings and the allocation of logging units to landings that will minimize costs.

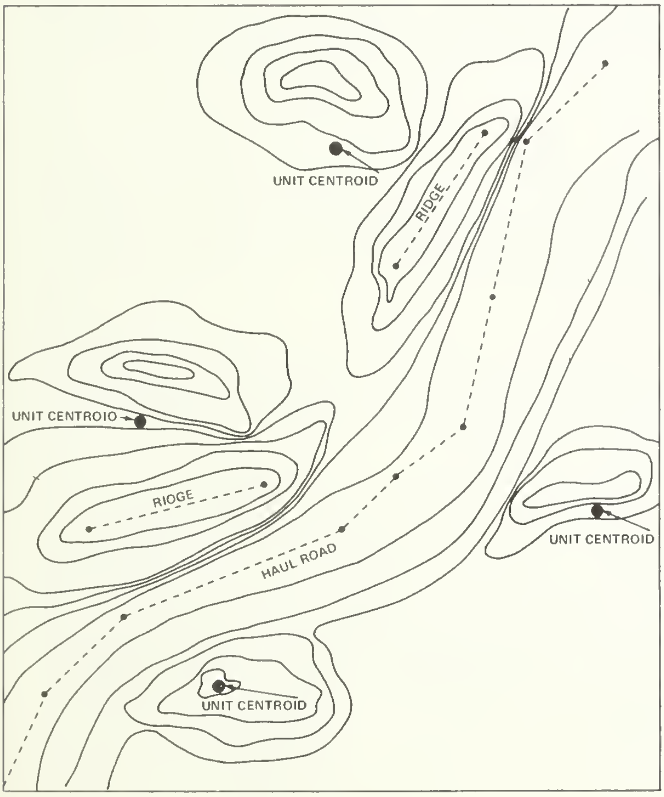

Figure 1.--A helicopter logging layout.

COMPUTER MODEL

Solution Procedure

A simplified flow chart of the landing location model is given in figure 2. Block 1 represents the input required for solution of the problem. This includes information concerning the units to be logged, the haul road, operating characteristics of the logging system, landing construction, hauling and operating costs, and topographic features of the area.

Block 2 represents the establishment of a scheme for allocating logging units to landings. For example, if three units are to be logged, timber in the first unit may be yarded to one landing and timber in the other two units may be yarded to a second landing. Another allocation scheme would be to yard all timber to one landing. The program has the facility to search all possible allocation schemes or only a particular subset that the user is especially interested in.

Once an allocation scheme is fixed, the program then finds the best location for the specified landings. The program can search along the entire road for these locations or will search only specified points. In either case, it begins the search by fixing a location. This operation is represented by block 3.

Next, flight paths and distances between the units and the landings are determined. When direct flight paths are precluded because of ridges or other obstacles, the flight path is determined to be the shortest distance composed of two linear line segments around the obstacle, as shown in figure 3. (This operation is represented by block 4 in figure 2.). Euclidean distances (including elevation) are used. In a situation similar to that shown in figure 3, since the centroid is used in describing the average flight path, all timber in the unit is routed around the ridge. If the ridge runs through a unit between the road and the centroid, the analyst may wish to define two units, one on each side of the ridge.

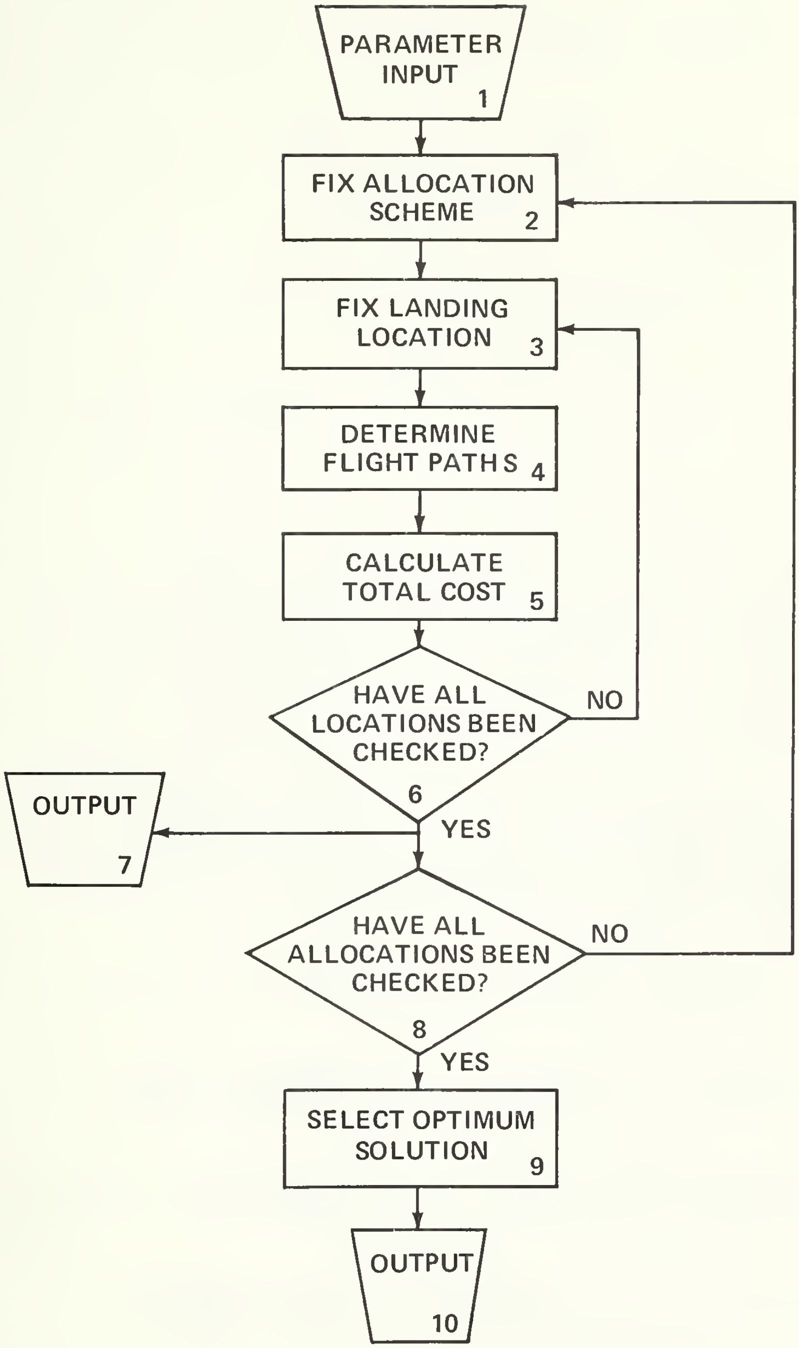

Figure 2.--Simplified flow chart of landing location model.

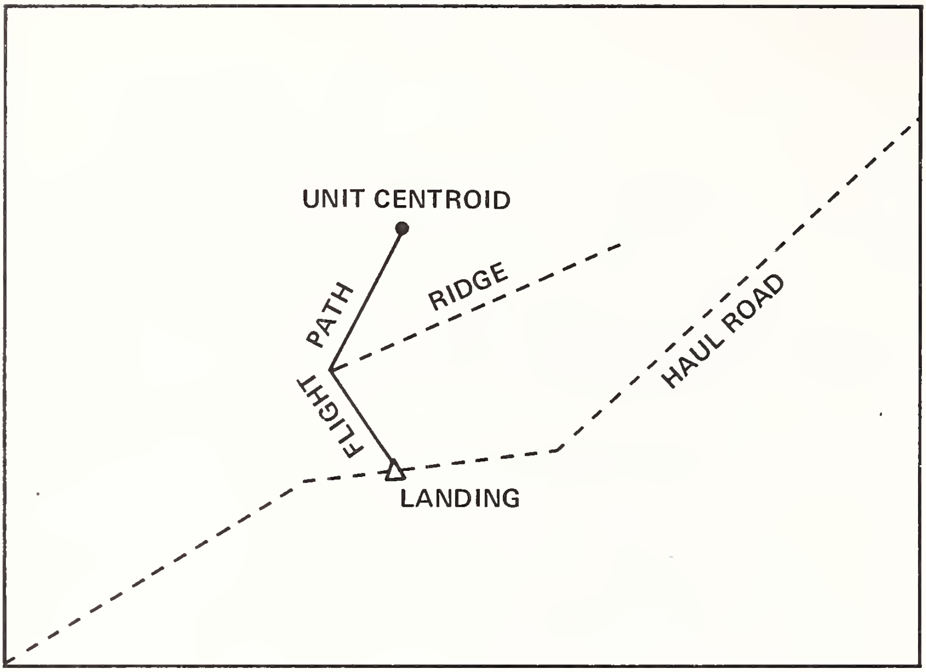

Figure 3.--Helicopter flight path around obstacle.

Total costs for the allocation scheme and location under consideration are then calculated as represented by block 5. Included are yarding costs, landing construction costs, and hauling costs. Abbreviated formulas for each of these are given in figure 4. Yarding costs include the consideration of the average speed of the helicopter when loaded and the average speed when empty. Landing construction costs can vary with location and have both fixed and variable (with weight yarded) components.

Block 6 of figure 2 signifies the program's check to see if all locations have been evaluated; if they have not, the cost of the next location is calculated. The next location can be at a specified increment along the road or at a particular location specified by the user. This process is continued until all locations have been evaluated for a given allocation scheme.

$$\text{YARDING COST} = \sum_{\text{UNITS}} \left(\text{DISTANCE} \div \text{SPEED} \times \frac{\text{COST}}{\text{TIME}} \times \#\ \text{TRIPS}\right)$$

$$\text{LANDING CONSTRUCTION COST} = \sum_{\text{LANDINGS}} (\text{FIXED COST} + \text{VARIABLE COST})$$

$$\text{HAULING COST} = \sum_{\text{LANDINGS}} \left(\text{DISTANCE} \times \#\ \text{TRIPS} \times \frac{\text{COST}}{\text{DISTANCE}}\right)$$

Figure 4.--Abbreviated cost equations.

Intermediate output of suboptimum solutions can be obtained as shown by block 7. That is, the program can, at the discretion of the user, print out the best solution for a given allocation scheme.

Once all locations have been evaluated for the current allocation and the minimum cost location has been selected, the program checks to see if all allocation schemes have been examined (block 8). If all schemes have not been evaluated, the process cycles back to block 2; otherwise the optimal solution is selected from previous calculations (block 9). Block 10 represents final output, which may be in several forms at the option of the user, including graphical plotting.

Program Input

The computer program, written in FORTRAN IV, is available on request from the Forestry Sciences Laboratory (ATTN: David F. Gibson), USDA Forest Service, Intermountain Forest and Range Experiment Station, P. O. Box 1376, Bozeman, Montana 59715. Input to the program is documented via comments; however, a more thorough explanation follows:

Card Type	Card Col.	Variable	Explanation
Card Set 1: Parameter Cards			
1			
Title Card	1-48	ITITLE	Any 48 alpha-numeric characters can be used to define the title of a particular run. This title will be printed as a heading on output from the line printer and as a caption on plots.
2			
Data Card	1-2	NUNIT	The number of units that are to be logged. (Maximum of 8.)
	3-4	NROAD	The haul road is defined as a set of linear line segments. NROAD is the number of linear line segments representing the road. (Maximum of 20.)
	5-6	NRWL	Certain segments of the road can be defined as infeasible locations for landings. NRWL is the number of such restricted segments. (Maximum of 10.)
	7-16	P	Average weight per load of the helicopter.
	17-26	OC	System operating cost expressed in $/min.
	27-36	SI	Average speed of helicopter when loaded expressed in ft/min.
	37-46	SO	Average speed of helicopter when unloaded expressed in ft/min.
	47-56	CPM	Cost to haul logs from landing to the mill expressed in $/mile.
	57-66	WPL	Average weight of truckload expressed in lb.

Card Type	Card Col.	Variable	Explanation
	67-76	XINC	XINC is the increment the program advances along the road in search of the optimum locations. (Expressed in feet.)
	77	IOUT	A variable to control the amount of output of the program. When IOUT = 0, the complete output is printed, which includes input values, the solution for each allocation scheme, and the optimal solution. If IOUT is set equal to 1, a printout of the input values and the optimal solution is made. A printout of only the optimal solution is given when IOUT = 2.
	78	IPLOT	This variable determines whether the optimal solution is drawn graphically by the CALCOMP plotter. If IPLOT = 1, a plot is made. If no plot is desired or a CALCOMP plotter is not available, set IPLOT = 0.
	79-80	NALT	Specific landing locations can be investigated using this variable. If NALT = 0, the road is searched every XINC ft for the best location. Otherwise NALT is the number of alternative landing locations to be tested.
3	This card is required only if IPLOT on card 2 is 1.		
Plot Card	1-2	NCOP	The number of copies of each plot desired.
	3-7	PH	The height in inches of the plot.
	8-12	PW	The width in inches of the plot.

Card Set 2: Unit and Ridge Cards. This card set contains unit and ridge constraint cards. There is one card for each unit. Therefore, there are I = 1, 2, ..., NUNIT unit cards in this set. In addition, there is one card for each ridge constraint, but a maximum of one ridge constraint per unit. Ridge constraint cards follow the unit cards for the unit to which they pertain.

Card Type	Card Col.	Variable	Explanation
1			
Unit Card	1-10	UX(I)	X - coordinate of unit I.
	11-20	UY(I)	Y - coordinate of unit I.
	21-30	UZ(I)	Z - coordinate of unit I (elevation).
	31-40	W(I)	Total weight of timber in unit I expressed in lb.
	41	IRC	If unit I has a ridge constraint associated with it, IRC is input as an R and then this card is immediately followed by a ridge constraint card.

Card Type	Card Col.	Variable	Explanation
2	This card type is required only if an R appears in column 41 of the preceding card.		
Ridge Constraint Card	1-10	RCX(I,1)	X - coordinate of beginning of ridge constraint on unit I.
	11-20	RCY(I,1)	Y - coordinate of beginning of ridge constraint on unit I.
	21-30	RCZ(I,1)	Z - coordinate of beginning of ridge constraint on unit I.
	31-40	RCX(I,2)	X - coordinate of end of ridge constraint on unit I.
	41-50	RCY(I,2)	Y - coordinate of end of ridge constraint on unit I.
	51-60	RCZ(I,2)	Z - coordinate of end of ridge constraint on unit I.

Card Set 3: Roadway Cards. This set of cards contains data pertaining to the linear line segments that define the road. This set is not required if NROAD (card set 1, card type 2, columns 3-4) is 0. That is, the program can be run without defining a road. In such a case, NALT would be greater than 0, and the analyst would be investigating a particular set of landing location alternatives.

Card Type	Card Col.	Variable	Explanation
1			
Origin Card	1-10	RX(0)	X - coordinate of beginning point of road.
	11-20	RY(0)	Y - coordinate of beginning point of road.
	21-30	RZ(0)	Z - coordinate of beginning point of road.
2	There must be one of these cards for each linear line segment.		
Segment Cards	1-10	RX(I)	X - coordinate of ending point of road segment I.
	11-20	RY(I)	Y - coordinate of ending point of road segment I.
	21-30	RZ(I)	Z - coordinate of ending point of road segment I.
	31-40	FC(I)	Fixed cost of constructing a landing on road segment I expressed in $.
	41-50	VC(I)	If the cost of a landing on road segment I is also dependent upon the amount of timber yarded to the landing, then the variable VC(I) can be employed to express this cost in terms of $/lb.

Card Type	Card Col.	Variable	Explanation

Card Set 4: Restricted Segment Cards. This set of cards defines those segments of the road where it is not possible to construct a landing. IF NRWL (card set 1, card type 2, columns 5-6) is 0, this set is not required. Otherwise there will be NRWL cards in this set, one for each restricted segment.

Card Type	Card Col.	Variable	Explanation
1			
Restricted Segment Cards	1-10	RXL(I,1)	X - coordinate of beginning of restricted segment.
	11-20	RLY(I,1)	Y - coordinate of beginning of restricted segment.
	21-30	RLX(I,2)	X - coordinate of end of restricted segment.
	31-40	RLY(I,2)	Y - coordinate of end of restricted segment.

Card Set 5: Alternative Landing Cards. The card set contains information about specific landing location alternatives the user may want to investigate. This set is not required if NALT (card set 1, card type 2, columns 79-80) is 0. Otherwise there will be NALT cards in this set, one for each alternative landing.

Card Type	Card Col.	Variable	Explanation
1			
Alternative Landing Card	1-10	ALTX(I)	X - coordinate of landing I.
	11-20	ALTY(I)	Y - coordinate of landing I.
	21-30	ALTZ(I)	Z - coordinate of landing I.
	31-40	FC(I)	The fixed cost of constructing a landing at location I expressed in $.
	41-50	VC(I)	The variable (with amount of timber yarded to the landing) cost of constructing a landing at location I expressed in $/lb.

Card Set 6: Allocation Scheme Cards. This card set may be repeated as many times as desired by the user, depending upon the number of allocation schemes to be investigated. A new set is required for each different number of landings investigated.

Card Type	Card Col.	Variable	Explanation
1			
Allocation Control Card	1	ID	The variable ID can be set equal to zero (blank) or input as A. If ID = 0, then the second card type will contain allocation matrix cards and the program will search all possible locations on the road for each allocation combination and minimize the total cost in deriving the best solution. If ID = A, the second card type will contain alternative allocation cards, and the program will compare and print the cost of specific location-allocation schemes.
	2-3	NLAND	The number of landings to be employed in the allocation scheme(s) defined in the second card type.
	4-5	NCOM	The number of allocation schemes to follow in the second card type.

Card Type	Card Col.	Variable	Explanation
2			
Allocation Matric Cards			This type of card is used only if ID = 0 (or blank). If ID = 0 (or blank), there will be NCOM cards of this type. Each allocation scheme will have a card whose entries are the elements of an allocation matrix. Rows represent units and columns represent landings. If unit I is to be assigned to landing J, then the I,J element of the matrix is 1, otherwise it is 0. Entries are read in by column with each entry allotted one card column. These entries can perhaps be best understood by considering the examples presented later in the text and the description given via comment cards in the program.
3			
Alternative Allocation Cards			This type of card is used only if ID = A. If ID = A, there will be NCOM cards of this type. Each allocation combination will have a card which will have NUNIT (number of units to be harvested) entries. The entry in the Ith column will be the alternative landing number to which unit I is to be yarded. These entries can be perhaps best understood by considering the examples presented.

Card Set 7: End of Job. The last card set contains one card, a blank card, which signifies that the problem input is complete. Problems can be run "back to back" by repeating card sets 1 through 7 successively.

Examples

Problem 1

As an example of the use of the model, consider the problem portrayed in figure 1. Figure 5 gives the layout with coordinates, elevations, and other data required for solution. Input to the problem as prescribed in the preceding section is illustrated on a FORTRAN coding sheet in figure 6. Output from the program on the line printer is given as figure 7. Since the input variable "IOUT" (column 77, card 2) was set equal to "0," complete output was obtained. That is, input data, intermediate solutions, and the optimal solution were printed out. The solution for case 7, when two landings are considered, indicates that both landings are in the same location. Since two landings were specified in the allocation scheme, the fixed cost is added twice. However, this solution, relative to location, should then be the same as for the allocation scheme with one landing. Indeed this is the case as indicated in the output. The output obtained from the plotter (obtained because input variable IPLOT, column 78, card 2, was set equal to 1) is shown in figure 8.

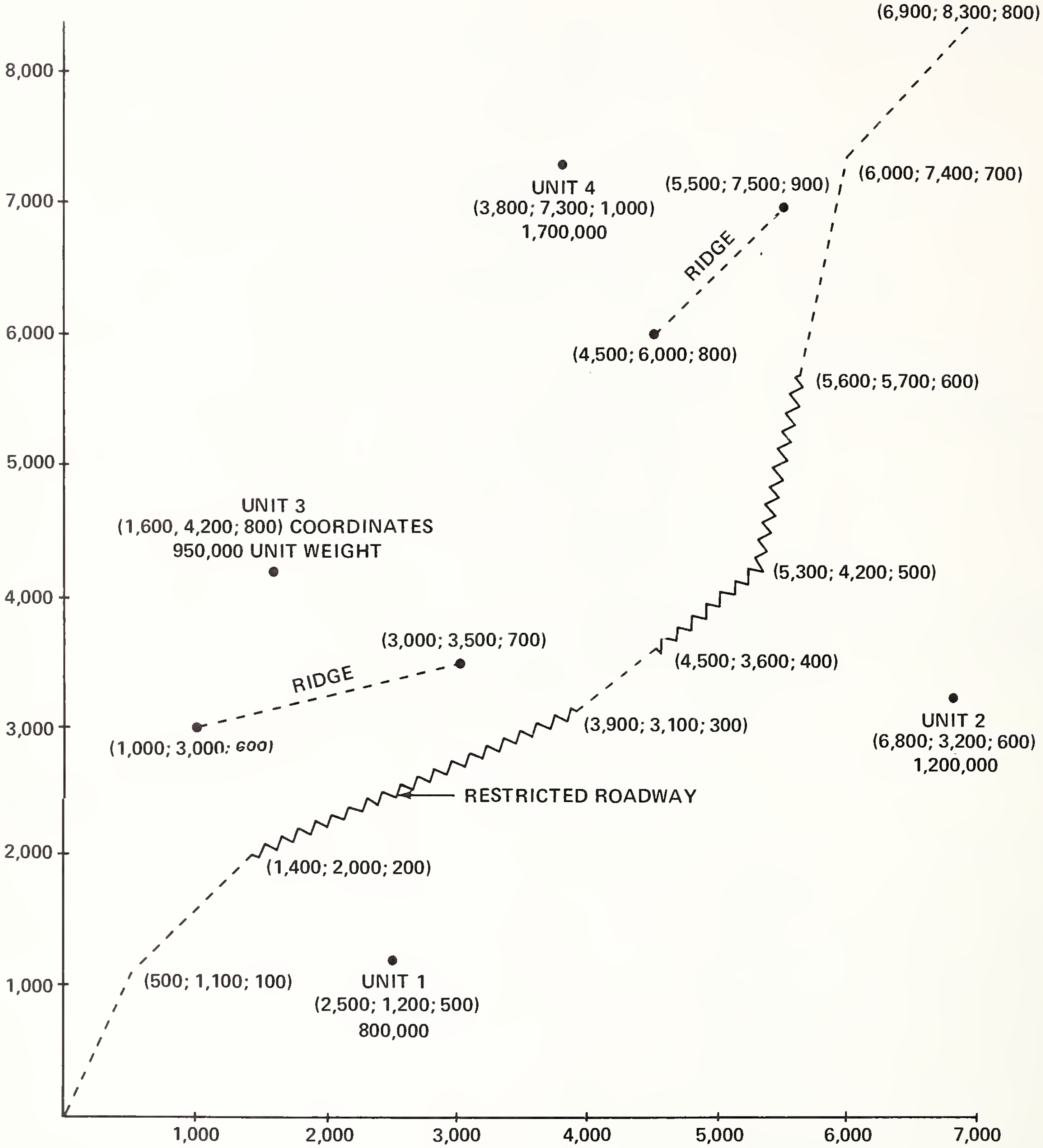

Figure 5.--Layout of helicopter logging problem 1 (from figure 1).

IBM FORTRAN Coding Form — GX28-7327-6 U/M 050** Printed in U.S.A.

```
EXAMPLE PRØBLEM #1
 4 8 2     8000.       18.     3000.     4000.       .40    60000.      100.01 0
 1  11.  8.5
     2500.     1200.      500.   800000.
     6800.     3200.      600.  1200000.
     1600.     4200.      800.   950000.R
     1000.     3000.      600.     3000.     3500.      700.
     3800.     7300.     1000.  1700000.R
     4500.     6000.      800.     5500.     7500.      900.
        0.        0.        0.
      500.     1100.      100.     1500.     .0001
     1400.     2000.      200.     1800.     .0001
     3900.     3100.      300.     1600.     .0002
     4500.     3600.      400.     1400.     .0
     5300.     4200.      500.     1100.     .0003
     5600.     5700.      600.     1300.     .0002
     6000.     7400.      700.     1300.     .0003
     6900.     8300.      800.     1300.     .0003
     1400.     2000.     3900.     3100.
     4500.     3600.     5600.     5700.
  4 1
1000010000100001
  3 6
110000100001
```

*A standard card form, IBM electro 888157, is available for punching statements from this form

**Number of forms per pad may vary slightly

IBM FORTRAN Coding Form — GX28-7327-6 U/M 050** Printed in U.S.A.

```
101001000001
100101000010
011010000001
010110000010
001110000100
  2 7
11100001
10110100
01111000
11010010
11000011
10100101
10010110
  1 1
1111
0000
```

*A standard card form, IBM electro 888157, is available for punching statements from this form

**Number of forms per pad may vary slightly

Figure 6.--Input data, helicopter logging problem 1.

Figure 7.--Line printer output, helicopter logging problem 1.

```
**** PROGRAM PARAMETERS ****

NUNIT NROAD NHWL    P             OC            SI            SC            CPM
  4      8     2   .8COCE C4    .1800E 02    .3COOF C4    .4OCCE 04    .400CE 00

WPL          XINC       IOUT IPLOT NALT NCOP   PH     PW
.60OCE C5   .1COOE C3   C     1      0     1   11.OC  8.5C

**** UNIT AND RIDGE CONSTRAINT CARDS ****

 I    UX(I)       UY(I)       UZ(I)       W(I)       IRC   RCX(I,1)
 1    .25CF C4    .12CE C4    .500E 03    .80OE C6         .COCE CC
 2    .68OF C4    .32OE C4    .600E 03    .12OF C7         .COCE CC
 3    .16CE C4    .42OE C4    .800E 03    .95OF C6  R      .10CE 04
 4    .38CE C4    .73OE C4    .100E 04    .17OF C7  R      .45CE 04

      RCY(I,1)    RCZ(I,1)    RCX(I,2)    RCY(I,2)    RCZ(I,2)
      .COCE OC    .OOCE CO    .COOE OC    .CCCE OC    .CCCE OO
      .COCE CC    .CCCE OC    .OOCE OC    .OOCE OC    .CCCE OO
      .30CE 04    .6CCE 03    .3CCE C4    .35CE 04    .7CCE 03
      .6OCE 04    .8OCE 03    .55CE C4    .75CE 04    .9CCE 03

**** ROADWAY CARDS ***

 I    RX(I)       RY(I)       RZ(I),       FC(I)       VC(I)
 C    .COOF CC    .COOE OC    .000E 00
 1    .50OF C3    .110E C4    .100E 03    .15OF C4    .1COE-C3
 2    .14OE C4    .20OE C4    .200E 03    .18OF C4    .1COE-C3
 3    .29OF C4    .31OE C4    .300E 03    .16OE C4    .2CCE-C3
 4    .45OF C4    .36OE C4    .400E 03    .14OE C4    .CCCE CO
 5    .53CE C4    .42OE C4    .500E 03    .11OE C4    .3COE-C3
 6    .56OF C4    .57OE C4    .600E 03    .13OE C4    .2CCE-C3
 7    .60OF C4    .74CE C4    .700E 03    .13OF C4    .3COE-C3
 8    .69OE C4    .83OF C4    .800E 03    .13OF 04    .3CCE-C3

**** RESTRICTED ROADWAY SEGMENTS ****

 I    RLX(I,1)    RLY(I,1)    RLX(I,2)    RLY(I,2)
 1    .14OE C4    .2COE C4    .39OE 04    .31OF C4
 2    .45OE C4    .36OE C4    .56OE 04    .57OF C4

*************************************************************      *******

        NUMBER OF UNITS =  4
        NUMBER  OF LANDINGS =   4

        *********************************************************

        CASE #  1:

             LANDING  COORDINATES(X,Y,Z)   UNIT DISTANCE
               #1     ( 1400, 2000,  200)   #1    1392 FT
               #2     ( 4500, 3600,  400)   #2    2343 FT
               #3     ( 3900, 3100,  300)   #3    2598 FT
               #4     ( 5989, 7354,  697)   #4    2263 FT
               YARDING COST = $  13443.47
               LANDING BUILDING COST = $     6429.99
               HAULING COST = $        39.89
             TOTAL COST = $  19913.36
```

```
**********************************************************************

        NUMBER OF UNITS =   4
        NUMBER  OF LANDINGS =   3

        *******************************************************

        CASE #   1:

             LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
               #1      ( 4437, 3548,   389)    #1     3046 FT
                                               #2     2397 FT
               #2      ( 3900, 3100,   300)    #3     2598 FT
               #3      ( 5989, 7354,   697)    #4     2263 FT
               YARDING COST = $   15264.70
               LANDING BUILDING COST = $      4610.00
               HAULING COST = $        43.24
             TOTAL COST = $   19917.94

        CASE #   2:

             LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
               #1      ( 1400, 2000,   200)    #1     1392 FT
                                               #3     2505 FT
               #2      ( 4500, 3600,   400)    #2     2343 FT
               #3      ( 5989, 7354,   697)    #4     2263 FT
               YARDING COST = $   13327.89
               LANDING BUILDING COST = $      5220.00
               HAULING COST = $        36.61
             TOTAL COST = $   18584.50

        CASE #   3:

             LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
               #1      ( 4437, 3548,   389)    #1     3046 FT
                                               #4     3854 FT
               #2      ( 4500, 3600,   400)    #2     2343 FT
               #3      ( 3900, 3100,   300)    #3     2598 FT
               YARDING COST = $   18728.51
               LANDING BUILDING COST = $      4260.00
               HAULING COST = $        34.08
             TOTAL COST = $   23022.59

        CASE #   4:

             LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
               #1      ( 4437, 3548,   389)    #2     2397 FT
                                               #3     2940 FT
               #2      ( 1400, 2000,   200)    #1     1392 FT
               #3      ( 5989, 7354,   697)    #4     2263 FT
               YARDING COST = $   13955.30
               LANDING BUILDING COST = $      4970.00
               HAULING COST = $        40.61
             TOTAL COST = $   18965.91

        CASE #   5:

             LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
               #1      ( 5600, 5700,   600)    #2     2773 FT
                                               #4     2647 FT
               #2      ( 1400, 2000,   200)    #1     1392 FT
               #3      ( 3900, 3100,   300)    #3     2598 FT
               YARDING COST = $   14976.89
               LANDING BUILDING COST = $      5330.00
               HAULING COST = $        40.08
             TOTAL COST = $   20346.97
```

```
CASE #  6:

     LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
       #1     ( 5600, 5700,   600)    #3    4276 FT
                                      #4    2647 FT
       #2     ( 1400, 2000,   200)    #1    1392 FT
       #3     ( 4500, 3600,   400)    #2    2343 FT
       YARDING COST = $  16392.63
       LANDING BUILDING COST = $    5315.00
       HAULING COST = $      40.22
     TOTAL COST = $  21747.86

*********************************************************************

     NUMBER OF UNITS =   4
     NUMBER  OF LANDINGS =  2

     *****************************************************

CASE #  1:

     LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
       #1     ( 3900, 3100,   300)    #1    2368 FT
                                      #2    2917 FT
                                      #3    2598 FT
       #2     ( 5989, 7354,   697)    #4    2263 FT
       YARDING COST = $  15372.19
       LANDING BUILDING COST = $    3210.00
       HAULING COST = $      41.45
     TOTAL COST = $  18623.65

CASE #  2:

     LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
       #1     ( 3900, 3100,   300)    #1    2368 FT
                                      #3    2598 FT
                                      #4    4259 FT
       #2     ( 4500, 3600,   400)    #2    2343 FT
       YARDING COST = $  18919.90
       LANDING BUILDING COST = $    2860.00
       HAULING COST = $      31.85
     TOTAL COST = $  21811.75

CASE #  3:

     LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
       #1     ( 4437, 3548,   389)    #2    2397 FT
                                      #3    2940 FT
                                      #4    3854 FT
       #2     ( 1400, 2000,   200)    #1    1392 FT
       YARDING COST = $  17504.07
       LANDING BUILDING COST = $    3160.00
       HAULING COST = $      31.33
     TOTAL COST = $  20695.40

CASE #  4:

     LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
       #1     ( 4437, 3548,   389)    #1    3046 FT
                                      #2    2397 FT
                                      #4    3854 FT
       #2     ( 3900, 3100,   300)    #3    2598 FT
       YARDING COST = $  18813.47
       LANDING BUILDING COST = $    2800.00
       HAULING COST = $      33.96
     TOTAL COST = $  21647.43

CASE #  5:

     LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
       #1     ( 4437, 3548,   389)    #1    3046 FT
                                      #2    2397 FT
       #2     ( 5600, 5700,   600)    #3    4276 FT
                                      #4    2647 FT
```

```
      YARDING COST = $  18213.86
      LANDING BUILDING COST = $    3495.CC
      HAULING COST = $        43.57
    TOTAL COST = $  21752.43

CASE #  6:

    LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
      #1     ( 1400, 2000,   200)    #1    1392 FT
                                      #3    2505 FT
      #2     ( 5600, 5700,   600)    #2    2773 FT
                                      #4    2647 FT
      YARDING COST = $  14861.31
      LANDING BUILDING COST = $    4120.CO
      HAULING COST = $        36.8C
    TOTAL COST = $  19018.11

CASE #  7:

    LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
      #1     ( 4437, 3548,   389)    #1    3C46 FT
                                      #4    3854 FT
      #2     ( 4437, 3548,   389)    #2    2397 FT
                                      #3    294C FT
      YARDING COST = $  19240.34
      LANDING BUILDING COST = $    2800.CC
      HAULING COST = $        34.8C
    TOTAL COST = $  22075.14

*******************************************************************************

    NUMBER OF UNITS =   4
    NUMBER  OF LANDINGS =   1

    ***********************************************************

CASE #  1:

    LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
      #1     ( 4437, 3548,   389)    #1    3C46 FT
                                      #2    2397 FT
                                      #3    294C FT
                                      #4    3854 FT
      YARDING COST = $  19240.34
      LANDING BUILDING COST = $    140C.CC
      HAULING COST = $        34.80
    TOTAL COST = $  20675.14


                 ****************************
                 *                          *
                 *  LANDING LOCATION MODEL  *
                 *      BEST SOLUTION       *
                 *                          *
*******************************************************************
*                                                                 *
*  NO OF UNITS =   4                                              *
*  NO OF LANDINGS =   3                                           *
*                                                                 *
*  ***********************************************************    *
*                                                                 *
*     LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE               *
*       #1     ( 1400, 2000,   200)    #1    1392 FT              *
*                                       #3    2505 FT              *
*       #2     ( 4500, 3600,   400)    #2    2343 FT              *
*       #3     ( 5989, 7354,   697)    #4    2263 FT              *
*       YARDING COST = $  13327.89                                *
*       LANDING BUILDING COST = $    5220.CC                      *
*       HAULING COST = $        36.61                             *
*     TOTAL COST = $  18584.50                                    *
*                                                                 *
*******************************************************************
```

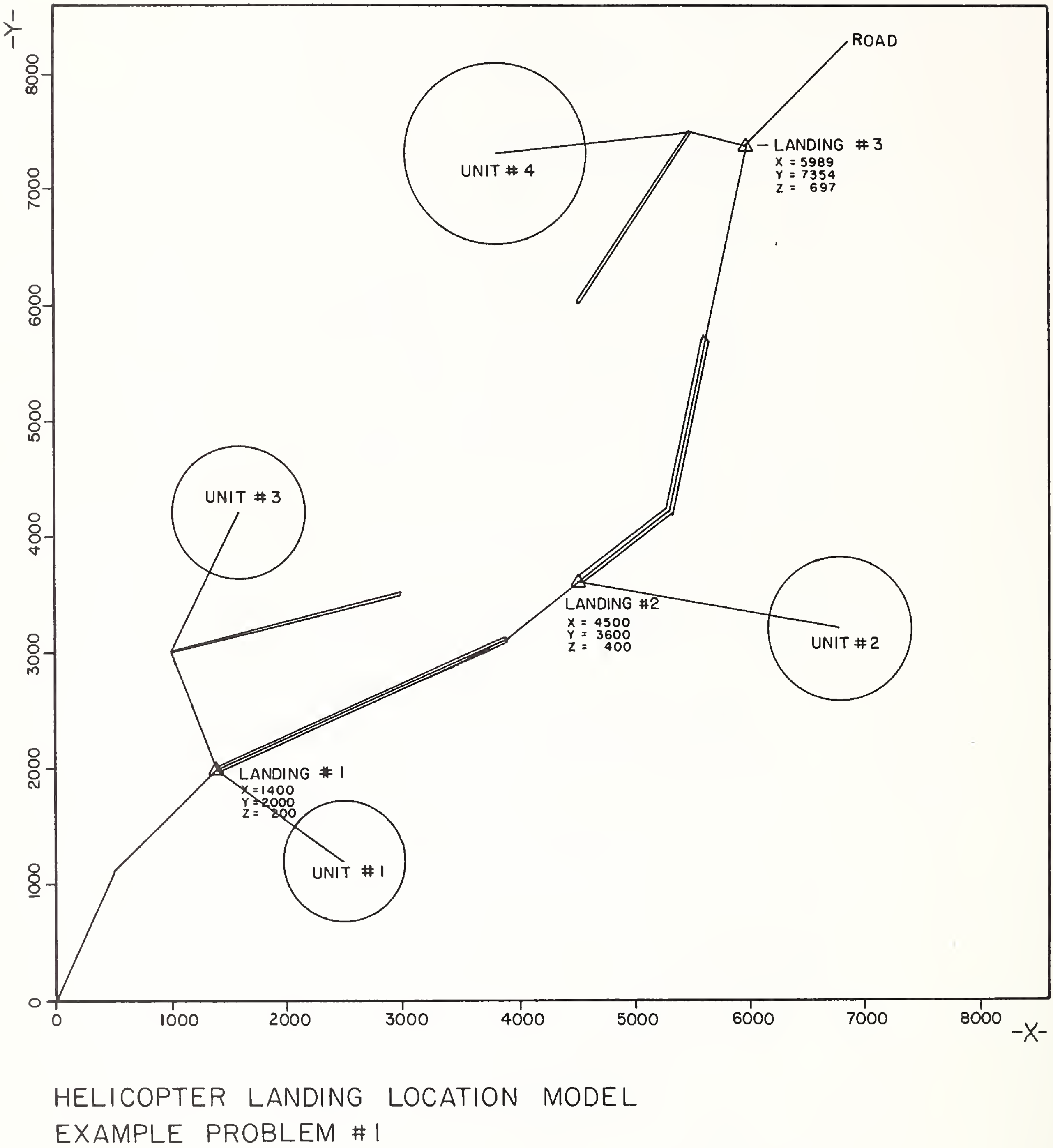

Figure 8.--Plotter output, helicopter logging problem 1.

Problem 2

In problem 1, the variable NALT (columns 79-80, card 2) was set to 0. Thus the program considered locations along the entire road in 100-foot increments (variable XINC, column 67-76, card 2) for potential landing locations. In problem 2, let us suppose that the analyst wished to consider only five specific locations on the road as possible alternatives. The alternative locations, and their respective landing building costs are given in table 1. Now evaluate several different allocation schemes; first, various allocation schemes utilizing two landings, and also four schemes utilizing three landings. These schemes are shown in table 2. Input format for this problem is illustrated on a FORTRAN coding sheet in figure 9. It should be noted that NALT (column 80, card 2) is now set equal to 5. Also note that landing costs do not have to be included on roadway cards since these costs are now associated with specific landings. Output of example problem 2 is given in figures 10 and 11 for the line printer and plotter, respectively.

Table 1.--*Alternative landing data*

Alternative	Coordinates	Fixed Cost	Variable Cost
1	(1,400; 2,000; 200)	1,600	0.0002
2	(4,500; 3,600; 400)	1,100	.0003
3	(5,600; 5,700; 600)	1,300	.0003
4	(6,000; 7,400; 700)	1,300	.0003
5	(6,450; 7,850; 750)	1,300	.0003

Table 2.--*Specific allocation schemes with three landings*

Scheme	Landing	Unit
1	1	1,3
	3	4
	5	2
2	2	1,3
	4	4
	5	2
3	1	1
	2	2
	3	3,4
4	1	3
	2	1,2
	4	4

IBM — FORTRAN Coding Form — GX28-7327-6 U/M 050** Printed in U.S.A.

```
EXAMPLE PRØBLEM #2
 4 8 2     8000.       18.     3000.     4000.        .40    60000.     100.01 5
 1  11.  8.5
     2500.     1200.      500.   800000.
     6800.     3200.      600.  1200000.
     1600.     4200.      800.   950000. R
     1000.     3000.      600.     3000.     3500.      700.
     3800.     7300.     1000.  1700000. R
     4500.     6000.      800.     5500.     7500.      900.
        0.        0.        0.
      500.     1100.      100.
     1400.     2000.      200.
     3900.     3100.      300.
     4500.     3600.      400.
     5300.     4200.      500.
     5600.     5700.      600.
     6000.     7400.      700.
     6900.     8300.      800.
     1400.     2000.     3900.     3100.
     4500.     3600.     5600.     5700.
     1400.     2000.      200.     1600.     .0002
     4500.     3600.      400.     1100.     .0003
     5600.     5700.      600.     1300.     .0003
     6000.     7400.      700.     1300.     .0003
```

*A standard card form, IBM electro 888157, is available for punching statements from this form.

**Number of forms per pad may vary slightly

IBM — FORTRAN Coding Form — GX28-7327-6 U/M050 Printed in U.S.A.

```
     6450.     7850.      750.     1300.     .0003
  2 5
11100001
01111000
11010010
11000011
10100101
A 3 4
1513
2524
1233
2214
0000
```

*A standard card form, IBM electro 888157, is available for punching statements from this form.

Figure 9.--Input data, helicopter logging problem 2.

Figure 10.--Line printer output, helicopter logging problem 2.

**** PROGRAM PARAMETERS ****

NUNIT	NRCAD	NRWL	P	OC	SI	SC	CPM
4	8	2	.8000E 04	.1800E 02	.3000E 04	.4000E 04	.4000E 00

WPL	XINC	IOLT	IPLOT	NALT	NCOP	PH	PW
.6000E 05	.1000E 03	0	1	5	1	11.00	8.50

**** UNIT AND RIDGE CONSTRAINT CARDS ****

I	LX(I)	LY(I)	LZ(I)	W(I)	IRC	RCX(I,1)
1	.250E 04	.120E 04	.500E 03	.800E 06		.000E 00
2	.680E 04	.320E 04	.600E 03	.120E 07		.000E 00
3	.160E 04	.420E 04	.800E 03	.950E 06	R	.100E 04
4	.380E 04	.730E 04	.100E 04	.170E 07	R	.450E 04

RCY(I,1)	RCZ(I,1)	RCX(I,2)	RCY(I,2)	RCZ(I,2)
.000E 00	.000E 00	.000E 00	.000E 00	.000E 00
.000E 00	.000E 00	.000E 00	.000E 00	.000E 00
.300E 04	.600E 03	.300E 04	.350E 04	.700E 03
.600E 04	.800E 03	.550E 04	.750E 04	.900E 03

**** ROADWAY CARDS ***

I	RX(I)	RY(I)	RZ(I),	FC(I)	VC(I)
0	.000E 00	.000E 00	.000E 00		
1	.500E 03	.110E 04	.100E 03	.000E 00	.000E 00
2	.140E 04	.200E 04	.200E 03	.000E 00	.000E 00
3	.390E 04	.310E 04	.300E 03	.000E 00	.000E 00
4	.450E 04	.360E 04	.400E 03	.000E 00	.000E 00
5	.530E 04	.420E 04	.500E 03	.000E 00	.000E 00
6	.560E 04	.570E 04	.600E 03	.000E 00	.000E 00
7	.600E 04	.740E 04	.700E 03	.000E 00	.000E 00
8	.690E 04	.830E 04	.800E 03	.000E 00	.000E 00

```
**** RESTRICTED ROADWAY SEGMENTS ****

 I    RLX(I,1)   RLY(I,1)   RLX(I,2)   RLY(I,2)
 1    .140E 04   .200E 04   .390E 04   .310E 04
 2    .450E 04   .360E 04   .560E 04   .570E 04


**** ALTERNATIVE LANDING LOCATIONS ****

 I    ALTX(I)    ALTY(I)    ALTZ(I)    FC(I)      VC(I)
 1    .140E 04   .200E 04   .200E 03   .160E 04   .200E-03
 2    .450E 04   .360E 04   .400E 03   .110E 04   .300E-03
 3    .560E 04   .570E 04   .600E 03   .130E 04   .300E-03
 4    .600E 04   .740E 04   .700E 03   .130E 04   .300E-03
 5    .645E 04   .785E 04   .750E 03   .130E 04   .300E-03


***********************************************************************

        NUMBER OF UNITS =   4
        NUMBER  OF LANDINGS =  2

        ***********************************************************

        CASE #   1:

             LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
               #2      ( 4500, 3600,   400)   #1    3125 FT
                                              #2    2343 FT
                                              #3    2988 FT
               #4      ( 6000, 7400,   700)   #4    2262 FT
               YARDING COST = $   15746.26
               LANDING BUILDING COST = $    3795.00
             TOTAL COST = $   19541.25

        CASE #   2:

             LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
               #3      ( 5600, 5700,   600)   #2    2773 FT
                                              #3    4276 FT
                                              #4    2647 FT
               #1      ( 1400, 2000,   200)   #1    1392 FT
               YARDING COST = $   17069.90
               LANDING BUILDING COST = $    4215.00
             TOTAL COST = $   21284.89

        CASE #   3:

             LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE
               #2      ( 4500, 3600,   400)   #1    3125 FT
                                              #2    2343 FT
                                              #4    3813 FT
               #1      ( 1400, 2000,   200)   #3    2505 FT
               YARDING COST = $   18604.26
               LANDING BUILDING COST = $    4000.00
             TOTAL COST = $   22604.25
```

```
CASE #  4:

     LANDING   COORDINATES(X,Y,Z)   UNIT DISTANCE
       #2     ( 4500, 3600,   400)   #1    3125 FT
                                     #2    2343 FT
       #3     ( 5600, 5700,   600)   #3    4276 FT
                                     #4    2647 FT
       YARDING COST = $   18212.14
       LANDING BUILDING COST = $   3795.00
     TOTAL COST = $   22007.13

CASE #  5:

     LANDING   COORDINATES(X,Y,Z)   UNIT DISTANCE
       #1     ( 1400, 2000,   200)   #1    1392 FT
                                     #3    2505 FT
       #3     ( 5600, 5700,   600)   #2    2773 FT
                                     #4    2647 FT
       YARDING COST = $   14861.31
       LANDING BUILDING COST = $   4120.00
     TOTAL COST = $   18981.31




**********************************************************************************************

NUMBER OF UNITS =   4
NUMBER OF ALTERNATIVE LANDINGS =   5

************************************************************************

CASE #  1:

  UNIT   ALTERNATIVE COORDINATES(X,Y,Z)   DISTANCE
   #1        #1      ( 1400, 2000,  200)    1392 FT
   #2        #5      ( 6450, 7850,  750)    4665 FT
   #3        #1      ( 1400, 2000,  200)    2505 FT
   #4        #3      ( 5600, 5700,  600)    2647 FT
       YARDING COST = $   17841.96
       LANDING BUILDING COST = $   5419.99
     TOTAL COST = $   23261.95

CASE #  2:

  UNIT   ALTERNATIVE COORDINATES(X,Y,Z)   DISTANCE
   #1        #2      ( 4500, 3600,  400)    3125 FT
   #2        #5      ( 6450, 7850,  750)    4665 FT
   #3        #2      ( 4500, 3600,  400)    2988 FT
   #4        #4      ( 6000, 7400,  700)    2262 FT
       YARDING COST = $   19404.17
       LANDING BUILDING COST = $   5094.99
     TOTAL COST = $   24499.16
```

```
CASE #   3:

  UNIT   ALTERNATIVE COORDINATES(X,Y,Z)   DISTANCE
   #1        #1       ( 1400, 2000,  200)   1392 FT
   #2        #2       ( 4500, 3600,  400)   2343 FT
   #3        #3       ( 5600, 5700,  600)   4276 FT
   #4        #3       ( 5600, 5700,  600)   2647 FT
      YARDING COST = $  16392.63
      LANDING BUILDING COST = $   5314.99
    TOTAL COST = $  21707.62

CASE #   4:

  UNIT   ALTERNATIVE COORDINATES(X,Y,Z)   DISTANCE
   #1        #2       ( 4500, 3600,  400)   3125 FT
   #2        #2       ( 4500, 3600,  400)   2343 FT
   #3        #1       ( 1400, 2000,  200)   2505 FT
   #4        #4       ( 6000, 7400,  700)   2262 FT
      YARDING COST = $  15144.11
      LANDING BUILDING COST = $   5299.99
    TOTAL COST = $  20444.10



                **************************
                *                        *
                *  LANDING LOCATION MODEL *
                *      BEST SOLUTION      *
                *                        *
****************************************************************
*                                                              *
*  NO OF UNITS =   4                                           *
*  NO OF LANDINGS =   2                                        *
*                                                              *
*  ********************************************************   *
*                                                              *
*      LANDING   COORDINATES(X,Y,Z)    UNIT DISTANCE           *
*        #1    ( 1400, 2000,  200)     #1    1392 FT           *
*                                      #3    2505 FT           *
*        #3    ( 5600, 5700,  600)     #2    2773 FT           *
*                                      #4    2647 FT           *
*        YARDING COST = $  14861.31                            *
*        LANDING BUILDING COST = $   4120.00                   *
*      TOTAL COST = $  18981.31                                *
*                                                              *
****************************************************************
*STOP* 0
```

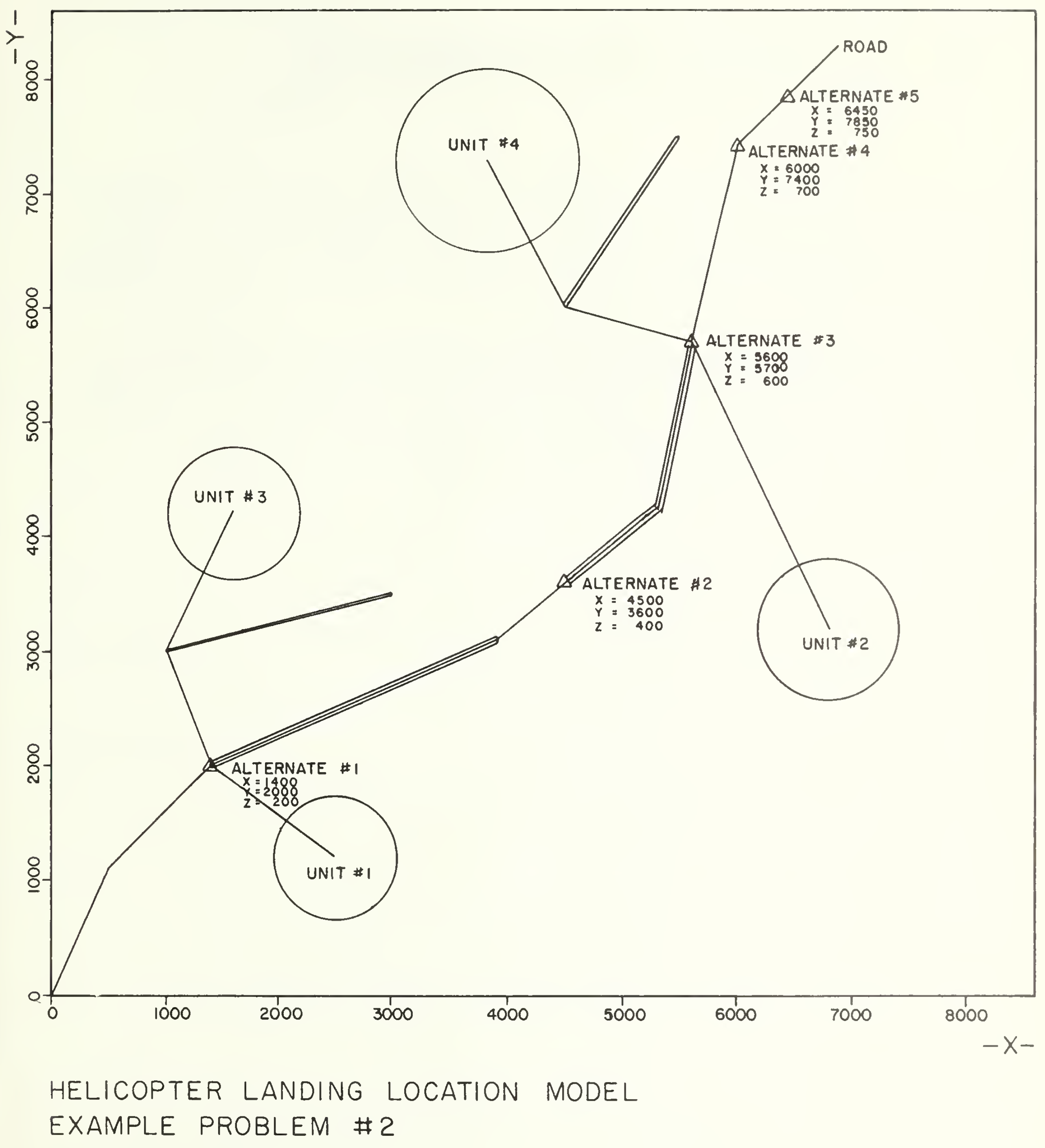

Figure 11.--Plotter output, helicopter logging problem 2.

Limitations

Limitations of the program with respect to the number of critical parameters are:

Parameter	*Maximum*
Number of units	8
Number of road segments	20
Number of restricted road segments	10
Ridges	1/unit

The first three limitations shown are imposed primarily to conserve storage requirements and can be easily increased. The fourth limitation is the number of ridge constraints that can be considered per unit. Presently, the program is limited to, at most, one ridge constraint per unit (units may have a common constraining ridge). This limitation cannot be altered easily, as a change would entail additional programing. Present capabilities will prove adequate for most helicopter logging sales.

When evaluating specific alternative landings (NALT >0), hauling costs are not calculated. Under this option, landings need not be located on an existing road, therefore actual hauling costs may be unknown until the location and cost are specified for a spur road from the haul road to the landing. As shown by the preceding examples, however, these costs generally prove to be very small as compared to landing and yarding costs.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1973 — 677-088 / 12 REGION NO. 8

EGGING, LOUIS T., and DAVID F. GIBSON
1974. Helicopter logging: a model for locating landings. USDA For. Serv. Res. Pap. INT-155, 27 p., illus. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

Presented are a model and an accompanying computer program that optimally locate landing areas for a helicopter logging operation. Given a haul road, unit centroids, volumes of timber to be harvested, and helicopter operating parameters, landings are located so as to minimize yarding, hauling, and landing construction costs. The model considers constraints such as areas that are not suitable for landings and topographical obstacles. Written in FORTRAN IV, the computer program affords several evaluation and output options. Two examples are provided.

OXFORD: 376:30.

KEYWORDS: helicopter logging, landing location, optimization.

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OXFORD: 376:30.

KEYWORDS: helicopter logging, landing location, optimization.

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)